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The 'carbon footprint' of sewer pipes: risks of inconsistency

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The sewerage industry needs to understand and reduce embodied carbon dioxide emissions associated with its assets in order to contribute to the national carbon dioxide reduction agenda. There are at least six recognised methodologies for calculating so-called 'carbon footprints' of construction products and tens of standard-based or ad hoc calculators. With the increase in information from different sources, the use of different methodologies and the absence of representative data and data collection methods, there is a risk that inappropriate data, results or methods are used to justify crucial decisions in the sewerage sector. This paper presents an assessment of the problem and its impact on the reliability of embodied carbon dioxide emissions data for large diameter (⩾225 mm) sewer pipes. Fifteen scenarios are developed based on a number of methodological rules and assumptions associated with data accuracy, functional unit, technology and geographic coverage. A significant variance, reaching over 50%, is found between widely accepted carbon footprint values for concrete and plastic sewer pipes and values based on alternative scenarios. Guidance is then offered on how secondary data should be handled and what methodological questions should be addressed prior to data use.

1. Introduction: the riddle of carbon footprinting

The case for the construction industry to address the embodied carbon dioxide emissions associated with construction is strong and clear. For example, the UK construction industry's carbon dioxide emissions make only around 7% of the country's total 'carbon footprint' (CF) (Hertwich and Peters, 2009); however, the overall influence of construction can potentially reach up to 47% (BIS, 2010). The same applies to the UK water and sewerage sector, in which it is believed that embodied carbon dioxide emissions from assets make up around a third of water companies' CFs (Cisholm, 2013), reaching up to 2·32 $MtCO_2e$ (metric tonnes of carbon dioxide equivalent) per annum, of which around 0·46 $MtCO_2e$ are associated with sewerage capital maintenance and construction of assets (Keil *et al.*, 2013). There is already evidence that water companies, under guidance from Ofwat (the water services regulation authority), are addressing operational as well as embodied carbon dioxide emissions. Anglian Water (2013) reported reductions to their embodied carbon dioxide emissions reaching 39% compared to a 2010 baseline. With carbon dioxide emissions reduction becoming a major consideration in tender selection in both the UK and internationally (Itoya *et al.*, 2012), it is becoming increasingly important for water companies to consider sustainability and carbon dioxide emissions in their decision-making process.

The last few years saw a rise in CF data generation across different sectors. Weidmann and Minx (2008) report that a simple search of the term 'carbon footprint' at the *Science Direct* portal yielded no more than 42 hits. This is compared to a total exceeding 1300 results in March 2011, 1991 results in May 2012 and 3453 results in May 2013. The high volume in the generation of academic and commercial carbon footprinting research has left a considerable wealth of CF data, including CFs for large-scale sewerage pipes over 225 mm in diameter (>DN225). For the water and wastewater sector, there is already a wealth of construction products' CF data with some dating back to the late 1990s. There are also a number of databases with such information, including the inventory of carbon and energy (ICE) by Bath University (Hammond and Jones, 2011), the Building Research Establishment (BRE) environmental profile database, Ecoinvent, GaBi database and INIES. However, with more emphasis on embodied carbon dioxide emissions in the water industry, there is an increasing need for the industry to account accurately for its embodied carbon dioxide emissions and review the wealth of embodied CF information currently available for use in assessing its projects.

The current embodied carbon dioxide calculation guideline for the water industry, published by UKWIR (UK Water Industry Research) in 2008 (UKWIR, 2008) and updated in 2012, was mainly based on a simplified method in which standardised emission conversion factors are multiplied by the quantity of materials used (Keil *et al.*, 2013). With that simplified standardised conversion method employed, it is difficult to ascertain whether all data quality and representativeness requirements, as set out in ISO 14044, section 4.2.3.6 (ISO, 2006), are being followed. It is also noted that the ICE method and database was considered as the default method/data source at the UKWIR's guide (Keil *et al.*, 2013). Considerable differences exist in CF values recorded by various databases and sources reaching up to 40% for some products: one example is the cradle-to-gate CF values for precast hollow-core flooring reported by Alexander *et al.* (2003) and Vares and Hakkinen (1998), which were 207·2 kg CO_2/t and 123·25 kg CO_2/t, respectively. This is despite the fact that both studies come from the same region in Europe (Scandinavia), with no more than 5 years, difference between the two publications.

Differences were also reported for generic CF values between widely known databases such as Ecoinvent and GaBi (Kreissig, 2012). This has led to a considerable level of confusion and concern within the life-cycle assessment (LCA) and carbon footprinting communities as the main standards for calculation of CF worldwide (ISO 14040, ISO 14044) are open to interpretation in many of its clauses and contain a number of grey areas (Weidema *et al.*, 2008). A number of these grey areas are identified by Finkbeiner (2009) including scope of emissions, life-cycle stages to be considered, system boundary conditions, offsetting and removals, data condition, allocation requirements, end-of-life (EoL) requirements, consideration of capital goods and renewable energy. Functional equivalence/functional unit is another area that can be decisive for the results of LCA, as demonstrated by Nierynck (1998).

These problems are aggravated by the fact that the water and wastewater industry will soon end up with four different standards and seven recognised methodologies to calculate construction products' CFs. In addition to the European Commission's newly introduced product environmental footprints (PEFs), CFs can be developed in accordance with PAS 2050 (BSI, 2008), World Business Council for Sustainable Development (WBCSD) greenhouse gas (GHG) protocol product standard (as a scope 3 emission), EN 15804 (CEN, 2012), ISO/TS 14067 or the original LCA series ISO 14040/44. All these are added to existing and well established methods or systems used by the UK water and wastewater construction market such as BRE's environmental profile methodology and the Bath University calculation system set for the ICE database. All these methods are being used to add to the wealth of CF information available on construction products used in the water and wastewater sector, and all can potentially lead to completely different CF values due to inherent differences in methodological rules and level of detail. In addition, some of these databases and methods have earlier versions, which may potentially also lead to different product CF values being publically available.

The ICE database, and its methodological framework, is being used as the main source and methodology at a number of industry calculators, guides and measurement systems, including UKWIR's guide and the Environment Agency's carbon calculator for construction projects (EA, 2012). It is still the most widely accepted source of CF data by the industry and has already been used by some water companies, such as Anglian Water, to make procurement decisions. However, it is unknown if data quality and representativeness checks are carried out by any users of the ICE database prior to its use. The significance of any corrections to align such standardised CF values with specific project requirements, and the impact of such corrections on water companies' procurement choice, is also largely unknown. This paper presents results from a study that assessed this problem by focusing on a number of elements affecting CF data for large scale sewerage pipes (⩾225 mm). The study focused on the main types of pipe used for such installations: These are concrete pipes and pipes made up of high density polyethylene (HDPE).

Generic CF data per one metre length of installed sewerage pipeline products (pipe sizes DN450, DN1200 and DN2100) are tested through a number of scenarios in which a number of methodological rules and assumptions are made in order to test how pipeline systems' CF values can be affected. The main factors influencing these CFs are then identified and advice is offered on what measures are needed in order to vet CF data for use by water companies.

2. Background: factors influencing the CFs of sewer pipeline systems

The CFs of large diameter (⩾DN225) sewerage and drainage pipeline systems can be affected by a number of methodology, boundary and data quality aspects. These issues are discussed below.

2.1 Goal, scope and functional unit

Studies and reports covering sewerage pipeline systems may often include some level of comparison between different underground solutions (e.g. whether to install a pipe using an open trench or a trenchless technology). However, these comparisons cannot be carried out unless the most appropriate level of functional equivalence, in light of that pipeline product's contribution to the overall system, is addressed. Choosing the right functional unit is important and will affect the overall findings of the study. The CF of a certain length of pipe is different to the CF of the same length of that pipe with joints, seals and bedding incorporated. Excavation of trenches can add up to 6·6 kg carbon dioxide for every m^3 of soil removed (Franklin Andrews Ltd, 2009). Adding excavation to the functional unit (as 1 m of installed pipeline) will mean that GHG emissions from fuel consumed by excavators and removal of soil away will be included to the overall CF and this can make it considerably higher.

2.2 Scope of emissions

Inclusion of all GHGs specified by the International Panel for Climate Change (IPCC, 2007), expressed in CO_2e, is recommended by the vast majority of standards addressing carbon footprinting. However not all databases are based on all GHGs emission information. One of the most popular databases for the construction industry in the UK (ICE database) used to report carbon dioxide-only footprints until 2011. Some water companies have already developed case studies for the embodied carbon of pipeline projects based on carbon dioxide emissions only. For concrete pipes there may not be a huge and considerable impact as differences between GHG and carbon dioxide-based footprints are no more than 6·7% for generic precast concrete (Hammond and Jones, 2011). However, 20–25% of GHG emissions for a polyethylene (PE) or PVC pipe is associated with methane (CH_4), making a huge difference between carbon dioxide and CO_2e-based footprints for these products (Boustead, 2005a, 2005b).

2.3 Life-cycle stages

While most methods and databases, such as ICE, EN15804 and PAS 2050, allow for cradle-to-gate CF, the default requirement for PEFs is cradle to grave (Manfredi *et al.*, 2012). Older studies based on the first version of PAS 2050 (BSI, 2008) used to offer cradle-to-site CFs as a minimum. This can make a considerable difference and might add a limitation on how CFs carried out in accordance with PAS 2050:2008 and PEFs can be used by the water industry. It should be noted that the functional unit for pipeline installations can differ depending on the scope and life-cycle stages considered.

2.4 Material nature and technology mix coverage issues

Cement contributes the most to the overall cradle-to-gate CF of concrete (Bijen, 2002; Hammond and Jones, 2011; Vares and Hakkinen, 1998) with contribution levels reaching well over 80%. However, concrete pipe mixes include cement combinations with high levels of fly ash replacing Portland cement use by 35%. This can have a considerable impact on the overall CF of the pipes as upsteam GHG emissions of fly ash are around 4–8 kg (carbon dioxide per tonne (CO_2/t)) (Hammond and Jones, 2011; MPA, 2012) compared to a CF of around 913 kg CO_2/t for CEM I Portland cement (MPA, 2012). Reinforcement can also have a significant impact as it can contribute over 10% of a cradle-to-gate CF.

CF of sewerage plastic pipes made of polyethylene or unplasticised PVC are also dominated by upstream GHG emissions associated with its original plastic resin, as demonstrated by a number of detailed studies and reports by Plastics Europe (Boustead, 2005a, 2005b). The studies jointly show how plastic pipe CFs can be affected by the type and grade of resin, and the location in which that resin is produced. However, recycled HDPE (as raw material) requires fewer energy-intensive processes with no significant upstream impacts, resulting in a generally lower CF value. Franklin Associates (2011) report a CF for recycled HDPE resin reaching 609 kg carbon dioxide equivalent per tonne (CO_2e/t) in the USA.

2.5 System boundary conditions

All CF quantification standards and methods specify different boundary conditions. Although most stressed that all primary activities should be included, cut-off and precision requirements differ considerably. PAS 2050 (BSI, 2011) and EN 15804 (CEN, 2012) accept an overall 5% cut-off rule, but PAS 2050 has base cut-off on impact while EN 15804 uses both mass and impact (e.g. energy). BRE's (2008) method has 2% of mass cut-off. The PEF (Manfredi *et al.*, 2012) and WBCSD GHG protocol methodologies do not specify cut-off, but the protocol proposes an insignificance estimate based on mass, impact or spend, but with no single cut-off limit reported (World Resources Institute, 2011). The ICE method is entirely different as it is based on secondary data from already existing studies. PAS 2050 and PEF currently have very detailed rules with regard to boundary conditions. The new PAS 2050 (BSI, 2011), PEF (Manfredi *et al.*, 2012) and EN 15804 (CEN, 2012) have requirements for some delayed carbon dioxide emissions and removals designed to eliminate some temporary effects (specifically targeting concrete and timber-based products).

2.6 Data condition

As generic secondary data are used frequently and are needed to complete the CFs of concrete and HDPE pipes, the level of reliability, representativeness and accuracy of such generic data is important. Schmidt (2009) argues that having a generic mean value in life-cycle inventory is false and misleading, he suggested that various types of technology or exact distribution distances should have no mean value or error, especially if a wrong decision is made based on the error margin associated with the mean value. The new PAS 2050 (BSI, 2011) sets a 10% minimum share for primary data to overall CF impact, but EN 15804 requires manufacturer processes to be based on primary data – which can account for around 10% and 20% of concrete and HDPE pipe CFs, respectively. CFs from the BRE method and database, GaBi and Ecoinvent databases are based on quality data for all main products, but much of its content is based on averages representative of the overall market as demonstrated by reports such as Weidema *et al.* (2013).

Geographical representation can have an impact on pipes' CF decision-making in a number of ways; for example, a lower number of concrete pipes is usually taken to site by a single truck than HDPE pipes. The main generic CF study for HDPE pipes in Europe (Boustead, 2005a) is based on a distance between the resin supplier and pipe manufacturer of no more than 100 km. This scenario may become implausible if western Europe becomes more reliant on Asian and Middle Eastern polyolefin imports, as demonstrated by recent commercial reports (ICIS, 2012; Nexant, 2009).

2.7 EoL requirements

In PAS 2050, PEF and ISO/TS 14067, EoL recyclability can attract benefits to products if a closed-loop EoL scenario is completed based on substitution of demand for primary virgin resource. The BRE method generally follows this approach with a value correction factor being employed as noted at Section 6.9.3.2 of their methodology manual (BRE, 2008). The ICE database method applies a 50:50 principle in which substitution impacts and benefits are allocated equally between the first and second product systems (Hammond and Jones, 2011). EN 15804 is the only standard that directly employs a 'recycled content' method, which does not fully integrate recyclability benefits into a product's CF (CEN, 2012). Both HDPE and concrete pipes can be affected by the EoL method employed as HDPE pipes can have up to 5% recycled content (CEN, 2007) and UK-produced concrete pipes incorporate reinforcement steel, which is 100% of recycled origins. The impact of such methodology assumption on the future recyclability of HDPE pipes is difficult to assess as 95% of plastic pipes used in sewerage may not be salvaged and recycled at the EoL (Teppfa, 2012a, 2012b).

3. Methodology: testing factors influencing sewerage pipeline CFs

The case study used to test the factors identified in this study is based on two studies. One on concrete pipes, which was carried out by Jones *et al.* (2010) as part of work by Carbon Clear Ltd for the Concrete Pipeline Systems Association (CPSA). It was done based on PAS 2050 (2011). The other study is about HDPE pipes and was carried out by Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (known as TNO) for Plastics Europe in 2005 (Boustead, 2005a) and updated in 2011 (Teppfa, 2011). The 2005 study was used as it contained more detailed inventory data. The 2011 study was not suitable as it was specifically for water mains systems. Both concrete and HDPE pipe case studies were reconstructed using an Excel sheet developed by Jones *et al.* (2010) for a comparative study. The case studies look primarily at CF for products imported and removed from construction sites (pipe, bedding and muck away), as demonstrated for concrete pipes in the flow diagram included in Figure 1. The pipe sizes explored were DN450, DN1200, DN2100 with narrow trench width conditions. Due to the range of pipe sizes considered, only concrete and HDPE pipes were included as these represent the vast majority for such size installations. With

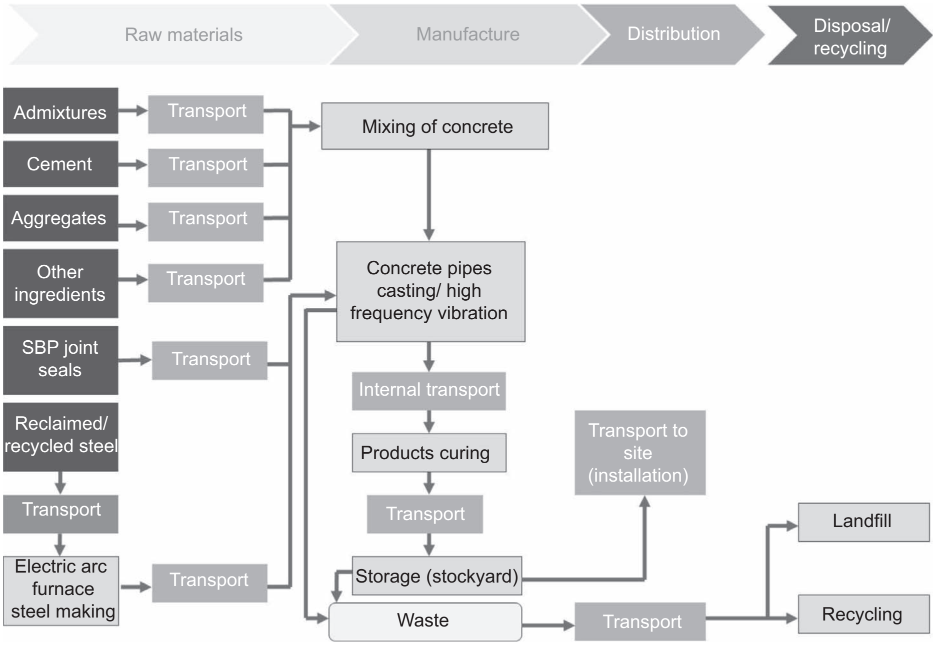

Figure 1. Process flow diagram for a cradle-to-gate CFP study for concrete pipeline products

the exception of scenarios 6.1 and 6.2, manufacturing sites were assumed to be 100 km away from construction sites. Quarries to import bedding materials, and landfill sites to dispose of excess ground material, were assumed to be 20 km away from construction sites. scenarios for sourcing internationally used Germany and India as raw material production locations owing to both countries' location at the centre of mainland Europe and Asia, respectively.

The scenarios were developed using the Jones *et al.* (2010) Excel sheets with additional applications and amendments included to test methodological assumptions. In addition to default scenarios 1.1 and 1.2, 12 other scenarios are included.

- Scenarios 1.1 and 1.2: default CF for concrete pipes and plastic pipes based principally on the two original studies currently being used by databases: Jones *et al.* (2011) and Boustead (2005a).
- Scenarios 2.1.1, 2.1.2 and 2.2: CF for concrete pipes with classes S and B bedding, and plastic pipes based on class S bedding.
- Scenarios 3.1 and 3.2: CF for concrete and plastic pipes with carbon dioxide emissions only.
- Scenarios 4.1 and 4.2: CF for concrete pipes with no cement replacement (CEM I based mix), and CF for plastic pipes with 5% recycled HDPE resin content.
- Scenarios 5.1, 5.2.1 and 5.2.2: CF for concrete pipes with the main raw material (cement) sourced from mainland Europe (Germany) and plastic pipes with the main raw material (HDPE resin) sourced from the UK (100 km from manufacturers) and from Asia (India), respectively.
- Scenarios 6.1 and 6.2: cradle-to-site CF for concrete and plastic pipes delivered to a construction site 750 km from the pipe manufacturing facility.
- Scenario 7.1: CF for concrete pipes using substitution-based recycled reinforcement steel CF.

The influence of methodological factors at each of the scenarios is demonstrated in terms of percentage deviation from the default scenario values.

4. Results and analysis

Results from the 15 scenarios tested show a wide variation in CF values. The results of all scenarios assessed are demonstrated in Figures 2–7.

4.1 Testing the consideration of functional unit

The bedding surround for a drainage/sewerage pipe is an integral part of the pipeline system, its structure and functionality. Figure 2 shows how scenarios for concrete and plastic pipes only (scenarios 1.1 and 1.2) compare with scenarios that include bedding surround. Accounting for the impact of pipe bedding makes the CF of a sewerage pipe 14–48% higher (depending on the pipe type, size and nature of bedding type). Scenarios 2.1.1 and 2.1.2 also show the significant savings that can be achieved if class B (which requires a 50% bedding surround for a concrete pipe) is used in place of class S (which requires full bedding surround). The results show that savings ranging from 7·7% (for DN2100) to 16·5% (for DN450) can be made by switching from a class S to class B bedding surround.

This clearly highlights the importance of using an appropriate functional unit when casting decisions based on CF information. Of the 0·46 $MtCO_2e$ associated with capital maintenance and construction of assets within the sewerage industry in the UK, cradle-to-gate concrete and plastic sewer pipes' CF may not make more than 7%. However, a more appropriate functional unit (allowing for bedding and installation impacts

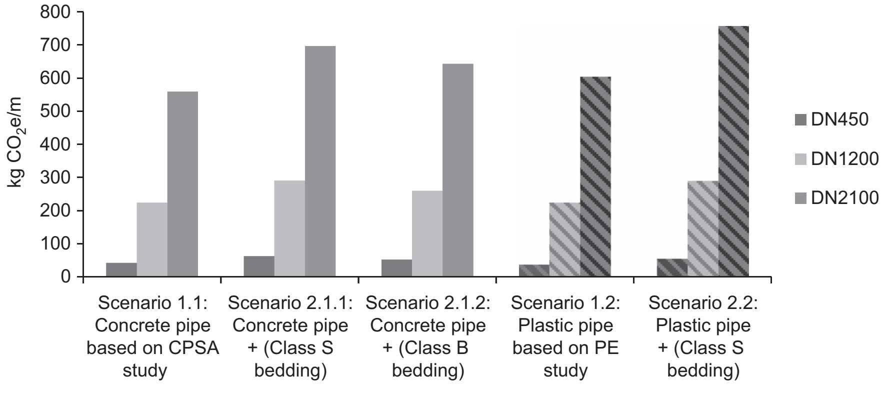

Figure 2. Baseline scenarios compared to different functional unit scenarios (kg CO_2e/m)

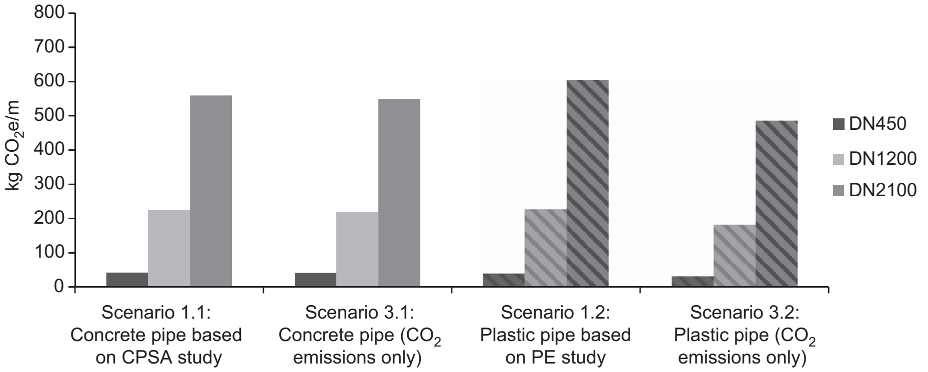

Figure 3. Baseline scenarios compared to carbon dioxide only scenarios (kg CO_2e/m)

to be accounted for) reveals a higher proportion associated with sewerage pipeline systems amounting to 9·1% of total capital maintenance and construction emissions. This highlights the importance of the approach recommended by EN 15804, which stresses that comparisons between construction products should only be carried out in the context of their application (CEN, 2012).

4.2 Testing the scope of GHG emissions

Figure 3 shows how scenarios 1.1 and 1.2 compare to scenarios for footprints based on carbon dioxide emissions only for plastic and concrete pipes (scenarios 3.1 and 3.2). The choice of whether to use an indicator accounting for all GHGs recognised under the Kyoto Protocol or carbon dioxide only should be straightforward. Most CF standards seem to point towards the use of a global warming potential (GWP) indicator, which recognises all main GHG emissions. However, a number of databases based on carbon dioxide only emissions still exist (e.g. ICE database, UK Building Blackbook). A direct comparison between GHG-based CFs and carbon dioxide only CFs reveals a difference of around 2% for concrete pipes and 20% for plastic pipes for all sizes tested. This clearly highlights the need for users of CF databases to be aware of what indicators are being used. However, it is important to note that the 20% value is based on values from a European study carried out in 2005 by Boustead (2005a) considering European resin only and a short resin sourcing distance (100 km). It should not be taken as a constant value applicable for all plastic pipe manufacturing scenarios.

4.3 Testing the effects of materials composition and mix

Two differing scenarios were considered for the case of concrete and plastic pipes. Figure 4 shows the two scenarios (scenarios 4.1 and 4.2) compared to scenarios 1.1 and 1.2. In the case of concrete pipes a scenario considering Portland cement only in the product's mix shows a CF value that is 32% (DN450) to 22% (DN1200) higher than the baseline scenario. This was by far the highest CF value for scenarios proposed for

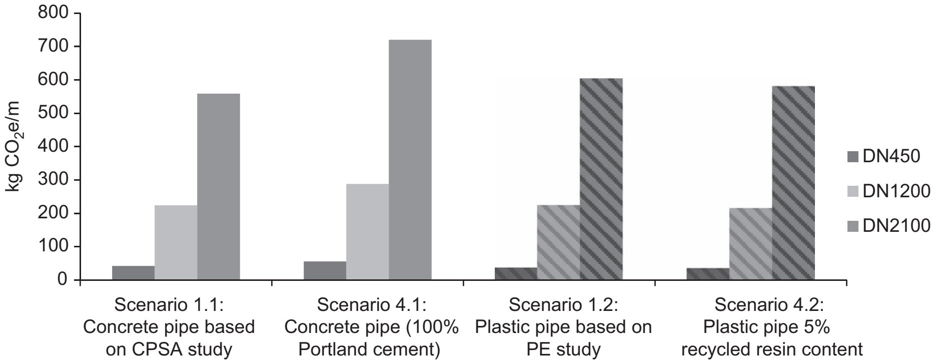

Figure 4. Baseline scenarios compared to different material mix scenarios (kg CO_2e/m)

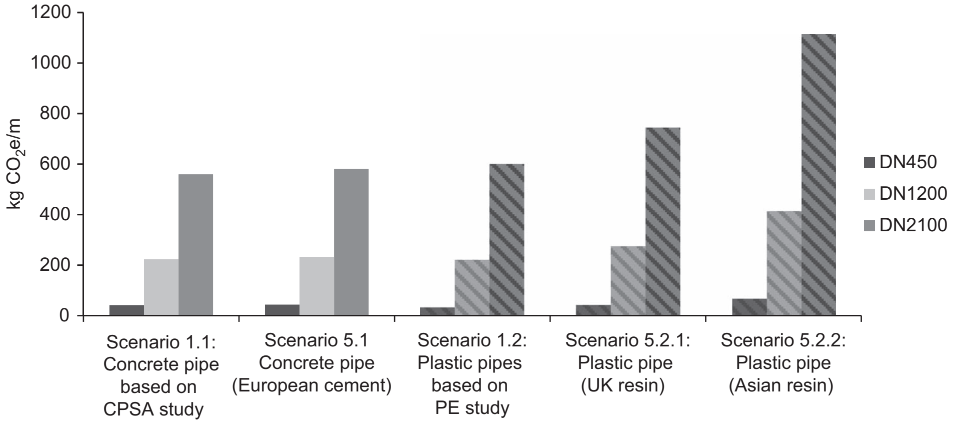

Figure 5. Baseline scenarios compared to different raw materials sourcing scenarios (kg CO_2e/m)

concrete pipes. In the case of a plastic pipe a scenario considering a maximum 5% recycled HDPE content, as recommended by EN 13476 (CEN, 2007), is considered. Compliance with that plastic pipe standard shows little change in CF value for plastic pipes reaching only 3·8%.

This scenario comparison underlines the importance of concrete mix and cement type consideration when conducting CF and LCA for pipeline systems studies. Use of data sourced from European databases will need to be scrutinised carefully prior to use as concrete pipes are not manufactured to the same mix throughout Europe. This clearly highlights the ISO 14044 (ISO, 2006) requirement for representativeness as a major data quality requirement to conduct LCA.

The same applies to the case of plastic pipes in which recycling requirements can differ from one EU state to another. Some thermoplastic pipes may not be manufactured in accordance with EN 13476 and could have a recycled content exceeding 5–10%.

4.4 Testing the impact of sourcing of raw materials

Figure 5 compares one concrete pipe and two plastic pipe sourcing and transport scenarios (scenarios 5.1, 5.2.1 and 5.2.2) with the baseline scenarios for concrete and plastic pipes. Scenario 5.1 shows an increase not exceeding 4% over the baseline scenario for all concrete pipe sizes considered, but scenarios 5.2.1 and 5.2.2 show a significant difference to scenario 2.1 reaching around 24% increase for scenario 5.2.1 and increase of around 85% to scenario 5.2.2.

This is because the three scenarios are affected (to different degrees) by contributions from transport and changes to the local electricity grid carbon dioxide intensity.

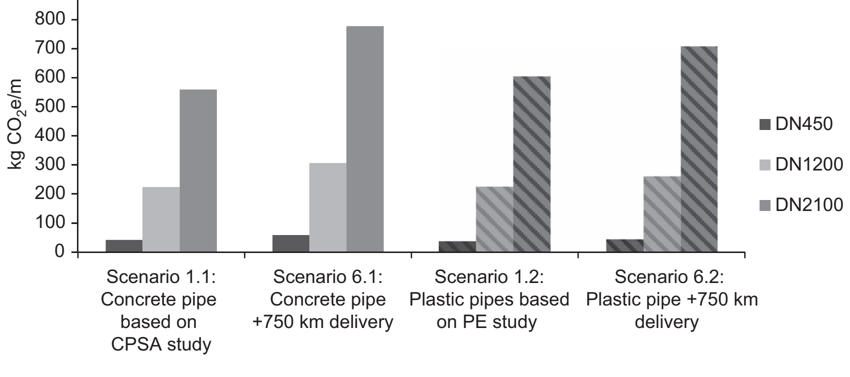

Figure 6. Baseline scenarios compared to cradle-to-site scenarios based on a delivery to site distance reaching 750 km (kg CO_2e/m)

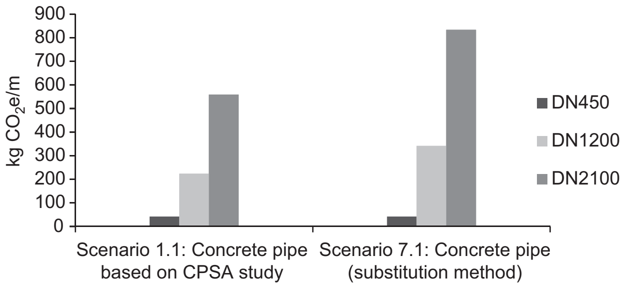

Figure 7. Concrete pipe baseline scenarios compared to substitution-based concrete pipe scenarios (kg CO_2e/m)

- The baseline 1.1 and 1.2 scenarios are based on sourcing distances of an average 95 km (for cement) and 100 km (for resin) for concrete and HDPE pipes, respectively. While scenario 5.2.1 uses the same distance, scenarios 5.1 and 5.2.2 will increase that distance considerably as cement will be sourced from 1018 km and HDPE resin will need a 13 836 km journey by sea.
- Scenario 5.1 was not affected by changes in electricity carbon dioxide intensity in a manner similar to scenarios 5.2.1 and 5.2.2. This is because electricity makes a relatively small component of the embodied carbon dioxide emissions of Portland cement. Moreover, the proportion of Portland cement used in concrete pipe mixes is not significant (10–12%) and the marginal difference between the German and UK electricity grid carbon dioxide intensity (around 0·49 and 0·54 kg CO_2/kWh, respectively) is also low. However, scenario 1.2 is based on a western European electricity grid carbon dioxide intensity (believed to be even lower than the 0·39 kg CO_2/kWh average) and electricity is a major component within thermoplastic resins' CF (Boustead, 2005c). Therefore, use of the higher UK and Indian grid carbon dioxide intensities (around 0·54 and 1·07 kg CO_2/kWh, respectively) had a significant effect on the overall CFs for scenarios 5.2.1 and 5.2.2

4.5 Testing the impact of pipes' travel distance to site

Figure 6 shows how the baseline scenarios compare to cradle-to-site scenarios where the pipes' delivery distance is 750 km. The results demonstrate how delivery to site can affect overall CF emissions (even at cradle-to-site level) as the CFs for concrete and plastic pipes increase by up to a maximum of 39% and 18%, respectively. This clearly highlights the need for the use of representative and realistic construction site delivery distances when making decisions based on CF information and accounting. In this specific scenario, the total length of pipes transported in a single truck-load has more impact on carbon dioxide emissions than the overall weight of such load.

4.6 Testing impact of methodology

Figure 7 shows how scenario 7.1 compares to the concrete pipe baseline scenario. Results show a significant rise in CF for two concrete pipe sizes (DN1200 and DN2100) by 53% and 49%, respectively. This clearly demonstrates how EoL considerations using the substitution method can make a significant change to results despite the fact that reinforcement makes a very small proportion of a concrete pipe's weight. DN450 concrete pipes are unreinforced and unaffected by this methodological rule.

5. Discussion and conclusion

Results from the scenarios considered clearly demonstrate how CF values for pipeline products can be affected by different methodological rules and assumptions. The scenarios show that the following questions can have a significant impact on the sewer pipes' CF calculation assumptions and decisions taken based on these assumptions.

- What method is used to account for the CF of metals and recyclates?
- What material mix is employed?
- Where are the finalised products or raw materials sourced from?
- What functional units are used?

The industry currently uses CF values for concrete and plastic pipes drawn from one main reference (ICE database) and employ them in a number of industry recommended databases and tools (such as UKWIR). The deviation from those 'standard' CF values (caused by different methodological scenarios) can reach around 53% for concrete pipes and 85% for plastic pipes. The deviation will increase significantly if more than a single factor was present. This can mean that the CF contribution of ⩾DN225 sewerage pipeline systems to assets maintenance and development in the sewerage sector may be significantly underestimated, or vice versa. In terms of the industry's fight against climate change, the consequences of making decisions based on inaccurate data can be serious. The industry may simply be focussing on the wrong hotspots.

Some of the methodological questions raised above may be sorted over time. There is already a direction within the construction industry to recommend EN 15804 (CEN, 2012) as the sole method to be used to calculate the embodied environmental impacts of construction products (HM Government, 2011), including CF. There will be more EN 15804 information, product category rules and CF data published in the future. This will help eliminate the complexities and disparities associated with methodologies and assumptions gradually. However, issues associated with scope, data representativeness and tendency to use 'generic' data can continue to pose difficulties and lead to inaccuracies in carbon accounting and measurement.

The scenarios demonstrated above reveal that supply chain can be a challenge. The standard and widely used CFs for concrete and plastic pipes are based on an assumption that the raw materials used in the production of concrete and plastic pipes are sourced no more than 95–100 km from the pipe manufacturers. However, although it may be a very small proportion, not all concrete pipeline products used in the UK are manufactured in Great Britain and not all precast products in the UK are made from locally produced cements and aggregates. Similarly, not all thermoplastic pipes and resins used in pipe production in the UK are sourced locally. There is already evidence that accurate measurement of emissions from the upstream of the supply chain (classified under 'Scope 3' within the GHG protocol) can potentially lead to unexpected results. Peters *et al.* (2011) reported an increase in emissions from the production of internationally traded goods and services from 4·3 Gt CO_2 in 1990 to 7·8 Gt CO_2 in 2008. A similar trend was also detected by Defra (2013) between 1997 and 2004, as carbon dioxide emissions from international trade rose by 23% during that period (despite dropping after the recession). This highlights the need to understand the nature of differences between individual suppliers of concrete and plastic pipes, which may currently be undetected owing to lack of sufficient information on products in the form of environmental product declarations (EPDs).

With the current level of CF data available, the sewerage and drainage sector is required to adopt some data quality measures to ensure that data and CF values used are as robust and representative as possible of the product or design solution. The sector also needs to ensure that consistent methodological rules and assumptions are adopted throughout. The idea of using generic databases with CF data needs to be assessed and debated by the industry as a switch to specific product EPDs is now needed. The ability of the industry to implement such change is crucial for more accurate carbon footprinting, and will prove to be vital to any decisions made in with regard to the carbon dioxide emissions reduction agenda.

The paper identifies variables that can have a significant impact on the carbon footprint of sewer pipeline products. It reveals that those variables can lead to differences in CF results reaching well over 50% of the widely accepted industry 'default' CF values. Specifiers, designers and contractors wishing to make decisions based on this carbon information will need to scrutinise any secondary data used to learn more about the CF methodology used and ensure that the values used are comprehensive, realistic, up to date and representative.

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